

SERIES OF ELECTROLYSIS CELLS FOR THE PRODUCTION OF ALUMINIUM  
COMPRISING MEANS FOR EQUILIBRATION OF THE MAGNETIC FIELDS AT THE  
ENDS OF THE LINES

Field of the invention

[01] The invention relates to the production of aluminium by means of fused bath electrolysis, i.e., by means of electrolysis of alumina dissolved in a molten cryolite bath, referred to as an electrolytic bath, according to the well-known Hall-Heroult process. The invention particularly relates to the equilibration of the magnetic field of series of rectangular electrolytic cells arranged transversally.

State of the art

[02] The plants for the production of aluminium by fused bath electrolysis contain a large number of electrolytic cells - typically several hundred - arranged in lines, and connected electrically in series using connecting conductors, so as to form two or more parallel lines which are connected together electrically by connecting conductors. The cells, which are rectangular in shape, can be oriented either longitudinally (i.e., such that their main axis is parallel with the main line axis), or transversally (i.e., such that their main axis is perpendicular to the main line axis).

[03] A large number of cells and connecting conductor arrangements have been proposed in order, firstly, to limit Joule effect losses and, secondly, to reduce the impact of magnetic fields produced by connecting conductors and the adjacent cells on the electrolytic process. For example, French patent application FR 2 552 782 (corresponding to US patent No. 4 592 821), held by Aluminium Pechiney, discloses a line of electrolytic cells arranged transversally that can operate industrially at intensities of more than 300 kA. According to this patent, magnetic cell stability is ensured by the configuration of the connecting conductors, particularly those passing under the pot. French patent application FR 2 583 069 (corresponding to US patent No. 4 713 161), also held by Aluminium Pechiney, discloses a line of electrolytic cells arranged transversally that can operate at intensities of up to 500 to 600 kA. According to this patent, the circuit construction and installation costs are minimised due to the use of

connecting conductors that are as small and direct as possible, while the magnetic stability and the Faraday yield are maximised through the use of independent correction conductors, arranged in parallel with each line and on either side thereof.

[04] The line arrangement of the electrolytic cells offers the advantage of simplifying the configuration of the connecting conductors and making the magnetic field map uniform. However, the presence of connecting conductors between the lines interferes with the uniformity of the magnetic fields of the end cells of each line.

[05] US patents Nos. 3 775 280 and 4 189 368 propose connecting conductor arrangements. However, these patents relate to series of cells arranged longitudinally comprising no correction conductors along the lines. In addition, the intensities of this type of cell do not generally exceed 100 kA.

[06] The European patent application EP 0 342 033 and Chinese patent application CN 2 477 650 disclose connecting conductor arrangements applicable to series of cells arranged transversally comprising no correction conductors along the lines. The interfering field is compensated by the arrangement of connecting conductors which produce an electric current along the end cell and in the vicinity thereof. These documents relate to series of electrolytic cells equipped with pots designed for intensities of the order of 300 kA.

[07] Therefore, the applicant researched economically and technically satisfactory ways to equilibrate the magnetic fields of series of cells formed from long rectangular cells, arranged transversally, equipped with a correction conductor along the internal side of the lines and designed for intensities greater than 300 kA.

#### Description of the invention

[08] The invention relates to a series of electrolytic cells intended for the production of aluminium by means of fused bath electrolysis according to the Hall-Heroult process, comprising:

- at least two lines of cells that are rectilinear and parallel with each other, wherein the cells are arranged transversally with a constant center distance  $E_0$  between the cells;

- a so-called "internal" correction circuit, comprising, for each line, at least one internal correction conductor, located along the line on the side thereof facing the neighboring line;
- a so-called "external" correction circuit, comprising, for each line, at least one external correction conductor, located along the line on the side thereof opposite the neighboring line;
- a so-called "main" connecting circuit between the end cell of one line and the corresponding end cell of the other line,

[09] and characterised in that, for at least one line:

- the main connecting circuit comprises a layer of conductors wherein each conductor extends from the end cell of the line to a determined distance ( $D_2$  and/or  $D_2'$ ) from the main axis C thereof, said distance ( $D_2$ ,  $D_2'$ ) being preferentially at least equal to once the center distance  $E_0$ ,
- the internal correction circuit also comprises a substantially rectilinear conductor, referred to as the "transverse segment", which is arranged perpendicularly with respect to the longitudinal axis of the line and located at a determined distance ( $D_1$  and/or  $D_1'$ ) from the end cell of the line, and which runs along said end cell over a determined fraction L of the length  $L_0$  of this cell.

[10] The applicant noted that, in the absence of magnetic field equilibration means, the line end cells are particularly affected by an additional mean vertical magnetic field  $\Delta B_z$ . The invention is thus intended to maintain the additional vertical field  $\Delta B_z$  within a range limited by a minimum value and a maximum value around a target value close to zero.

[11] The applicant also observed that the perturbation of the magnetic field map of the end cells of a line stemmed not only from the connecting conductors between the lines, but also the interruption of continuity and symmetry at the end of the lines.

[12] The applicant had the idea of equipping the series with a layer of conductors capable of simulating the presence of electrolytic cells beyond the end cell. It also had the idea of

introducing said transverse segment, at the end of the line, in order to compensate the magnetic field produced by the connecting conductors between the lines. The combination of these means makes it possible to equilibrate the magnetic fields at the pots of the electrolytic cells located at the connection end of a line (typically about the first 10 cells), i.e., correct the unfavorable magnetic field map produced by the connecting conductors. This combination particularly makes it possible to limit the vertical magnetic field  $B_z$  substantially in these cells. In addition, the use of a transverse segment in the internal correction circuit enables a more precise adjustment of the correction thanks to the additional adjustable parameters provided.

[13] The invention is described in detail hereinafter using the appended figures.

[14] Figure 1 represents, in a simplified manner and in a cross-sectional view, two typical successive electrolytic cells in a cell line.

[15] Figure 2 illustrates, schematically, a series of electrolytic cells according to the invention comprising two lines and an internal correction circuit.

[16] Figure 3 illustrates an electrolytic cell line end corresponding to figure 2.

[17] Figure 4 illustrates, schematically, a series of electrolytic cells according to the invention comprising two lines, an internal correction circuit and an external correction circuit.

[18] Figure 5 illustrates an electrolytic cell line end corresponding to figure 4.

[19] The invention relates to series of electrolytic cells 1 comprising, as shown in figure 1, a plurality of electrolytic cells 101, 102,... 101', 102' substantially rectangular in shape, which are arranged so as to form at least two lines F, F' of parallel substantially rectilinear cells, having each a longitudinal axis A, A'.

[20] In the figures, the electrolytic cells are designated by a reference number which increases from the line end cell. In this way, the end cell (or "first" cell) of each line is designated by the references 101 and 101', the "second" cell by the references 102 and 102', the "third" cell by the references 103 and 103', and so on.

[21] The cells 101, 102,... 101', 102',... are arranged transversally (i.e., such that their "main axis" C is perpendicular to the main axis A, A' of said lines) and located at the same

distance from each other, thus defining a constant center distance  $E_o$  between the main axes  $C$  of the adjacent cells of each line. The center distance  $E_o$  is typically between 5 and 8 metres. The main axis  $C$  of the electrolytic cells 101, 102,... 101', 102'... is defined as being the axis of symmetry which is parallel with their long sides 18a, 18b. The long sides 18a, 18b of each cell 101, 102,... 101', 102',... have a length  $L_o$  and the short sides 19e, 19i a width  $R_o$ . The length  $L_o$  is substantially greater than the width  $R_o$ . The cells of the series according to the invention typically have a length  $L_o$  greater than three times the width  $R_o$ .

[22] The lines  $F$ ,  $F'$  are separated by a distance  $D_o$ , the value of which depends on technological choices which particularly account for the current intensity  $I_o$  of the series and the conductor circuit configuration. The distance  $D_o$  is typically between 40 and 100 m.

[23] As illustrated in figure 1, each electrolytic cell 101, 102,... 101', 102',... of the series 1 typically comprises a pot 3, anodes 4 supported by attachment means typically comprising a stem 5 and a multipod 6 and connected mechanically and electrically to an anode frame 7 using connection means 8. The pot 3 comprises a metal shell, generally reinforced by stiffeners, and a crucible formed by refractory materials and cathode elements arranged inside the shell. The shell generally comprises vertical lateral walls. In operation, the anodes 4, typically made of carbon-containing material, are partially immersed in an electrolytic bath (not shown) contained in the pot. The pot 3 comprises a cathode assembly 9 equipped with cathode rods 10, typically made of steel, wherein one end 11 emerges from the pot 3 so as to enable an electrical connection to the connecting conductors 12,... 17 between cells.

[24] The connecting conductors 12,... 17 are connected to said cells 101, 102,... 101', 102',... so as to form an electrical series, which forms the main electrical circuit 100 of the series of electrolytic cells. The connecting conductors typically comprise flexible conductors 12, 16, 17, upstream connecting conductors 13 and rising sections 14, 15. Figure 2 illustrates the case of a connecting circuit comprising 5 rising sections (as in French patent application FR 2 552 782). Figure 4 illustrates the case of a connecting circuit comprising 8 rising sections (as in French patent application FR 2 583 069). The upstream connecting conductors may, completely or partially, pass under the pot and/or bypass it.

[25] The series of electrolytic cells according to the invention also comprises at least one electrical correction circuit independent from the series and running along the so-called "internal" side of the cells, i.e., the side located on the side of the neighboring line. In the embodiment illustrated in figures 2 and 3, the series 1 of cells comprises a single electrical correction circuit 200, referred to as the "internal circuit". In the embodiment illustrated in figures 4 and 5, the series 1 of cells comprises two electrical correction circuits that are separate and independent from the series, i.e., a first correction circuit, referred to as the "internal circuit" 200, and a second correction circuit, referred to as the "external circuit" 300.

[26] The internal correction circuit 200 comprises at least one conductor 20, 20' referred to as the "internal correction conductor" and located along each line on the side thereof facing the neighboring line. This conductor is typically substantially rectilinear and parallel with the longitudinal axis A, A' of each line. The circuit also comprises at least one internal connecting conductor 21 to ensure the electrical continuity between the internal correction conductors 20, 20' of each line. The short side of the cells located on the side of the internal correction conductor 20, 20' is referred to as the internal side 19i.

[27] Similarly, the external correction circuit 300 comprises at least one conductor 30, 30', referred to as the "external correction conductor" and located along each line on the side opposite the neighboring line. This conductor is also typically substantially rectilinear and parallel with the longitudinal axis of each line. The circuit also comprises at least one connecting conductor 31 to ensure the electrical continuity between the external correction conductors 30, 30' of each line. The short side of the cells located on the side of the external correction conductor 30, 30' is referred to as the external side 19e.

[28] In operation, the electrolytic current, of an intensity  $I_o$ , flows in the series 1 of cells and a correction current, of an intensity  $I_i$ , flows in the internal correction circuit 200. If the circuit also comprises an external correction circuit, a first correction current, of an intensity  $I_i$ , flows in the internal correction circuit 200 and a second correction current, of an intensity  $I_e$ , flows in the external correction circuit 300. The direction of these currents is typically that indicated by the corresponding arrows in figures 2 and 4.

[29] In this way, according to the invention, the series 1 of electrolytic cells, which is intended for the production of aluminium by means of fused bath electrolysis according to the Hall-Heroult process, comprises:

- a plurality of electrolytic cells 101, 102,... 101', 102'... arranged so as to form at least one first F and one second F' lines of cells that are rectilinear and parallel with each other, said cells 101, 102,... 101', 102'... being arranged transversally with the longitudinal axis A, A' of each line with a constant center distance  $E_0$  between the cells, each cell 101, 102,... 101', 102'... having a length  $L_0$ ;
- connecting conductors 12,... 17 between the cells of each line;
- a so-called "internal" correction circuit 200, comprising at least one first internal correction conductor 20, located along the first line on the side thereof facing the second line, one second internal correction conductor 20', located along the second line on the side thereof facing the first line, and at least one so-called "internal" connecting conductor 21;
- a so-called "main" connecting circuit 400 between the end cell 101 of the first line and the end cell 101' of the second line,

[30] and characterised in that, for at least one of said lines:

- the main connecting circuit 400 comprises at least one layer of conductors 40, 40' wherein each conductor 401, 401' is connected to the end cell 101, 101' of the line and extends to a determined distance  $D_2$ ,  $D_2'$  therefrom,
- the internal correction circuit 200 also comprises at least one rectilinear conductor 23, 23', referred to as the "transverse segment", which is connected to the internal correction conductor 20, 20', is arranged perpendicularly with respect to the longitudinal axis A, A' of the line and runs along the end cell 101, 101' of the line, at a determined distance  $D_1$ ,  $D_1'$ , over a determined portion L of the length  $L_0$  of the end cell.

[31] As illustrated in figures 3 and 5, the determined portion or "fraction"  $L$  is calculated using an imaginary line extending from the short internal side 19i of the cell. The determined portion  $L$  is preferentially greater than  $0.5 L_o$  and more preferentially greater than  $0.8 L_o$ . Each transverse segment 23, 23' advantageously runs along the entire length  $L_o$  of the end cell ( $L$  is equal to  $L_o$  in this case. The term "each" as used in this application should be interpreted to include situations where only one thing is involved (in these situations, "each" also will mean "the") and situations in which more than one thing is involved.

[32] The distances  $D1$  and  $D1'$ , along with the distances  $D2$  and  $D2'$ , may be different for each line.

[33] The line which comprises the magnetic field equilibration means according to the invention is said to be "compensated". Preferentially, each line of the series is compensated according to the invention, i.e. each line comprises at least one layer of conductors 40, 40' and the internal correction circuit 200 comprises at least one transverse segment 23, 23' according to the invention.

[34] Said first 20 and second 20' internal correction conductors are preferentially rectilinear and parallel with the longitudinal axis  $A, A'$  of the lines. They are typically located at a determined distance  $D_i$  from the external side of the cells (i.e. typically at a determined distance  $D_i$  from the vertical surface of the metal wall of the pot shell). The value of the determined distance  $D_i$  is typically less than 1 metre. The correction conductors 20, 20' are typically located at the level of the pots 3.

[35] The main connecting circuit 400, which ensures the electrical continuity between the two lines of cells, typically comprises at least one so-called "transverse" connecting conductor 43 which is preferentially arranged perpendicularly with respect to the longitudinal axis  $A, A'$  of the lines and at a determined distance  $D3$  from the end cell 101, 101' of the lines.

[36] Each layer of conductors 40, 40' is located on the side of the connecting circuit 400 and covers, preferentially, at least 80%, and more preferentially at least 90%, of the length  $L_o$  of the cells 101, 102,... 101', 102',... Each layer 40, 40' is advantageously plane. The conductors 401, 401' of each layer 40, 40' are advantageously distributed uniformly (i.e., so as to



be parallel and located at the same distance from each other) and, typically, similarly to those of the rising sections 14, 15. The individual conductors 401, 401' of the layer 40, 40' are typically connected to the end cell 101, 101' by longitudinal connecting conductors 12a, 12b to which conductors 13 from the near long side 18a and/or the far long side 18b of the cell are connected. Several connecting conductors 11, 12, 13 may be connected to the same individual conductor 401, 401' of the layer.

[37] The main connecting circuit 400 advantageously comprises at least one joining conductor 41, 41', to which the conductors 401, 401' of the layer 40, 40' are connected. In order to simplify the embodiment of the connecting circuit, each joining conductor 41, 41' is preferentially rectilinear, arranged perpendicularly with respect to the longitudinal axis A, A' of the lines and located at said determined distance D2 and/or D2'. The length of the joining conductor 41, 41' is preferentially substantially equal to the width W of the layer 40, 40'.

[38] Advantageously, the main connecting circuit 400 also comprises a connecting conductor 42, 42' connected to the joining conductor 41, 41', on one hand, and to the transverse connecting conductor 43, on the other, in order to ensure the electrical continuity between these conductors. The connecting conductor 42, 42' is preferably longitudinal, i.e. rectilinear and parallel to the longitudinal axis A, A' of the line, and located at a determined distance of said axis. The connecting conductor 42, 42' may be connected to the center of the joining conductor 41, 41', i.e., in the axis of each line, in order to ensure electrical equilibrium of the circuit and maintain the symmetry of the main connecting circuit with respect to the longitudinal axis A, A' of the line. The connection may be located towards the inside or towards the outside of the lines, with respect to the longitudinal axis A, A', in order to create additional compensation asymmetry.

[39] The internal connecting conductor 21 preferentially comprises a so-called "transverse" conductor arranged perpendicularly with respect to the longitudinal axis of the lines A, A' and at a determined distance D4 from the end cell 101, 101' of the lines. In this configuration, the internal correction circuit 200 also comprises intermediate connecting conductors 22, 22', 24, 24', which comprise internal intermediate conductors 22, 22' and external intermediate conductors 24, 24'. The internal intermediate conductors 22, 22' extend advantageously from the corresponding internal correction conductors 20, 20' and extend

preferentially at least to each determined distance D1 and/or D1'. This embodiment makes it possible to extend the symmetry of the specific conductors for the line and thus limit the perturbations of the magnetic field caused by the interruption in continuity of the series at the end of the line.

[40] The series according to the invention may also comprise if required a so-called "external" correction circuit 300, comprising at least one first external correction conductor 30, located along the first line on the side thereof opposite the second line, one second external correction conductor 30', located along the second line on the side thereof opposite the first line, and one so-called "external" connecting conductor 31. The first 30 and second 30' external correction conductors are preferentially rectilinear and parallel with respect to the longitudinal axis A, A' of the lines. They are typically located at a determined distance De from the external side of the cells. The value of the determined distance De is typically less than 1 metre. The correction conductors 30, 30' are typically located at the level of the pots 3.

[41] The external connecting conductor 31 preferentially comprises a so-called "transverse" conductor arranged perpendicularly with respect to the longitudinal axis of the lines A, A' and at a determined distance D5 from the end cell 101, 101' of the lines. In this configuration, the external correction circuit 300 also comprises, for each line, at least one external intermediate connecting conductor 32, 32'. These intermediate conductors 32, 32' extend advantageously from the corresponding external correction conductors 30, 30'. They extend to the determined distance D5 which is, preferentially, at least equal to each determined distance D1 and/or D1'. This embodiment makes it possible to extend the symmetry of the specific conductors for the line and thus limit the perturbations of the magnetic field caused by the interruption in continuity of the series at the end of the line.

[42] The external intermediate conductors 24, 24' of the internal correction circuit 200 are typically parallel with the intermediate conductors 32, 32' of the external correction circuit 300. These conductors may be separated by a very small distance E, which may be less than 1 metre.

[43] The transverse connecting conductors 21, 31, 43 are advantageously rectilinear in order to simplify their design and limit their cost.

[44] The distances D1 to D5 are determined with respect to the longitudinal axis, or "main axis", C of the end cell 101, 101' which is located on the side of the connecting conductors.

[45] The distances D3, D4 and D5 and preferentially as large as possible. It was found to be sufficient for the value of these distances to be greater than or equal to determined thresholds S3, S4, S5. In fact, for distance values greater than these thresholds, the circuits according to the invention make it possible to compensate for the impact of the additional magnetic field induced by the connecting conductors 21, 31, 43 between lines. The value of the thresholds S3, S4 and S5 depends on the intensity of the electrolytic current  $I_o$ , the intensity of the correction currents  $I_i$  and  $I_e$ , and the value of the total additional magnetic field  $\Delta B_z$  deemed acceptable. The distances D3, D4 and D5 are typically greater than or equal to 5 times the distance D1, D1' of the transverse segment 23, 23'.

[46] The distances D3, D4 and D5 are advantageously of the same order of magnitude, i.e., there is very little difference between them (i.e., typically less than 20% with respect to each other, or even less than 10%), in order to simplify the embodiment of the circuits. In this case, the applicant found that the value of the thresholds S3, S4 and S5 was given by the approximate equation  $S3 = S4 = S5 \cong K \times I_o \times (\Delta B_z / B_o)^\alpha$ , where K is a constant,  $\alpha$  is a constant between -1 and -0.2,  $\Delta B_z$  is given in Gauss and  $B_o = 1$  G.

[47] The determined distance D1, D1' of the transverse segment 23, 23' is selected so as to compensate for the impact of the additional magnetic field induced by the connecting conductors 21, 31, 43 between lines. More specifically, the determined distance D1, D1' is preferentially such that the additional magnetic field added by all the conductors to the specific field corresponding to an endless line is limited between a maximum value  $+\Delta B_z$  and a minimum value  $-\Delta B_z$  at the level of the end cells of a line, particularly the end cell 101, 101'.

[48] The determined distance D2, D2', which is typically that of the joining conductor 41, 41', is preferentially at least equal to once the center distance  $E_o$ , and more preferentially at least equal to twice the center distance  $E_o$ .

[49] The values of the determined distances D1 and D1' or D2 and D2' are typically substantially the same for each compensated line.

Example 1

[50] The applicant performed a calculation simulating a series of at least 200 electrolytic cells formed by two parallel lines separated by a distance  $D_0$  of approximately 50 m. The electrical circuits had a similar configuration to that in figures 2 and 3. The longitudinal connecting conductors 42, 42' were connected to the center of the corresponding joining conductors 41, 41'. The length of the cells was 15 m. The transverse segment 23, 23' covered the entire length of the last cell (i.e., a fraction  $L$  equal to 1). The center distance between the cells was 6 m. The circuit comprises 5 rising sections separated from each other by 2.7 metres. The layer of conductors 40, 40' comprises 5 conductors at intervals of 2.7 metres.

[51] The intensities were as follows:  $I_o = 350$  kA and  $I_i = 30$  kA.

[52] The applicant found that  $K \cong 0.13$  m/kA and  $\alpha \cong -0.44$ .

[53] It was also noted that, using the following parameters, the intensity of the additional vertical magnetic field  $\Delta B_z$  at the center of the end cells of each line could be made less than 5 Gauss for distances  $D_3$ ,  $D_4$  and  $D_5$  equal to 24 m, distances  $D_1$  and  $D_1'$  equal to 3.5 m and distances  $D_2$  and  $D_2'$  at least equal to 6 m.

Example 2

[54] The applicant performed a calculation simulating a series of at least 200 electrolytic cells formed from two parallel lines separated by a distance  $D_0$  of approximately 85 m. The electrical circuits had a similar configuration to that in figures 4 and 5. The longitudinal connecting conductors 42, 42' were connected to the center of the corresponding joining conductors 41, 41'. The length of the cells was 18 m. The transverse segment 23, 23' covered the entire length of the last cell (i.e., a fraction  $L$  equal to 1). The center distance between the cells was 6 m. The circuit comprised 8 rising sections separated from each other by 2 metres. The layer of conductors 40, 40' comprised 8 conductors at intervals of 2 metres.

[55] The intensities were as follows:  $I_o = 480$  kA,  $I_i = 180$  kA and  $I_e = 105$  kA.

[56] It was noted that, in the absence of magnetic field equilibration means, the mean additional vertical magnetic field  $\pm\Delta B_z$  on the first end cells of each line is between 5 and 14 Gauss, in absolute values.

[57] The applicant found that  $K \cong 0.17 \text{ m/kA}$  and  $\alpha \cong -0.58$ .

[58] It was also noted that, using the following parameters, the intensity of the additional vertical magnetic field  $\Delta B_z$  at the center of the end cells of each line could be made less than 5 Gauss for distances D3, D4 and D5 equal to 32 m, distances D1 and D1' equal to 6 m and distances D2 and D2' at least equal to 6 m.

[59] The applicant observed that the layer simulates the presence of the cell missing after the end of the lines sufficiently well so that the end cells are not subject to excessive perturbation.